Field Study on Removal of Dissolved Metals from Parking Lot Runoff by Catch-basin Filters Augmented with Media Containing Water Treatment Residuals

Sunhawach Na Nagara
Dr. Dibyendu Sarkar
Dr. Virinder Sidhu
Stevens Institute of Technology
Hoboken, NJ

Dr. Kirk Barrett, PE
Mott MacDonald
Iselin, NJ

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Project #: 6610-0015

Problem:
Heavy metals and petroleum hydrocarbons in stormwater runoff from roads and parking lots

Objectives:

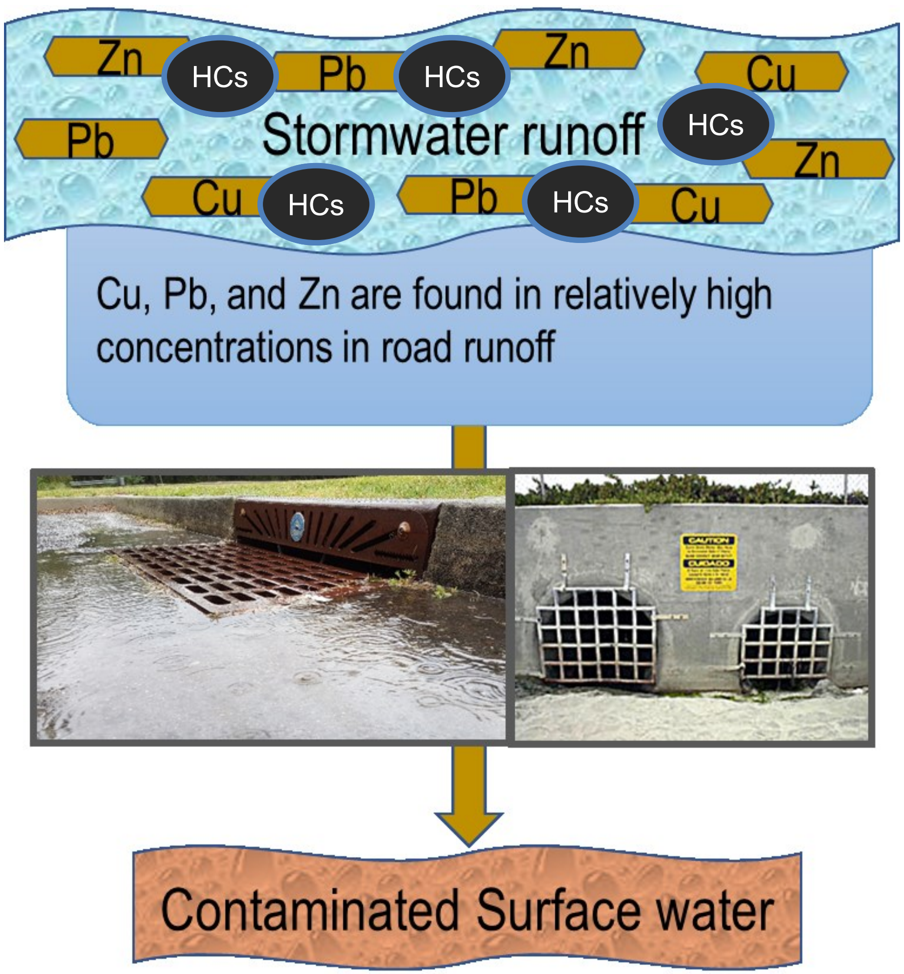
1) In the lab, determine optimum a mixture for an adsorbent media comprising water treatment residuals and sand

2) Test the mixture in the field

Heavy metals and petroleum hydrocarbons are commonly found in low concentrations in road runoff

- **Cu:**
  pavement wear and brake linings
- **Pb:**
  car batteries and exterior paints
- **Zn:**
  car tires, atmospheric fallout, exterior paint, and building sidings
- **Petroleum Hydrocarbons:**
  gasoline, diesel, and engine oil

Heavy Metals and Petroleum Hydrocarbons in Road Runoff



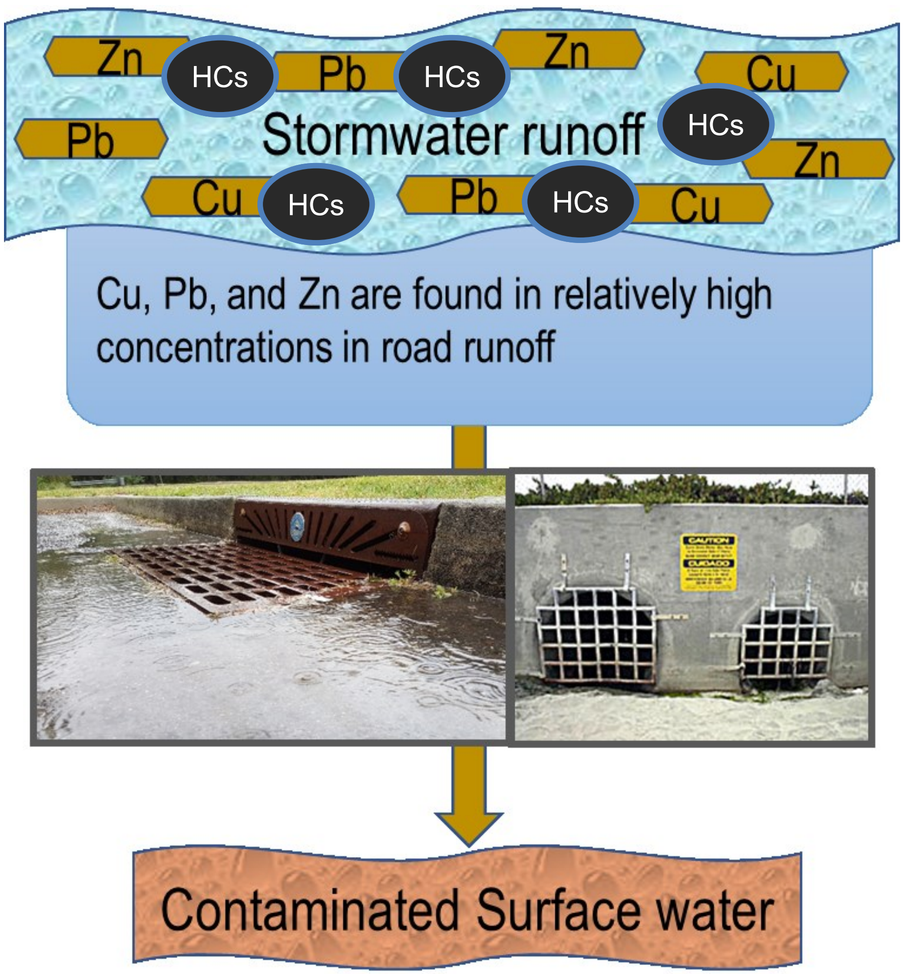
Harmful Characteristics of Heavy Metals

- Accumulation in the environment
- Non-biodegradability
- Biomagnification
- Toxicity

Harmful Characteristics of Petroleum Hydrocarbons

- Toxicity
- Forming thin-film on water surfaces

Heavy Metals and Petroleum Hydrocarbons in Road Runoff



Adverse impacts

- Affecting reproduction rates and life spans of aquatic species
- Disrupting food chains in aquatic systems
- Affecting water supplies

Table 2. Top Causes of Metal Impairments
(Source: EPA 2011b)

Cause of Impairment	Impaired Waterbodies
Mercury (including sediment and tissues)	3,767
"Metals" (other than mercury)	2,606
Lead	861
Copper	826
Iron	607
Arsenic	527
Zinc	470
Selenium	378
Manganese	340
Cadmium	276
Aluminum	245
Silver	93
Nickel	63
Chromium	53
Other metal listings (other than mercury) (including metals in sediment and tissues)	116

Table 4. Typical Levels of Metals Found in Stormwater Runoff (ug/L)
(Source: *Fundamentals of Urban Runoff Management*, Shaver et al. 2007)

Metal	Stormwater Median (90th Percentile)[a]	Mean (sd)[b]	Median (Cov) Urban Stormwater[c]	Range for Highway Runoff[d]	Range for Parking lot Runoff[e]
Arsenic	n/a	5.9 (2.8)	3.3 (2.42)	0-58	n/a
Cadmium	n/a	1.1 (0.7)	1.0 (4.42)	0-40	0.5-3.3
Chromium	n/a	7.2 (2.8)	7.0 (1.47)	0-40	1.9-10
Copper	34 (93)	33 (19)	16.0 (2.24)	22-7033	8.9-78
Lead	144 (350)	70 (48)	15.9 (1.89)	73-1780	10-59
Mercury	n/a	n/a	0.2 (1.17)	0-0.322	n/a
Nickel	n/a	10 (2.8)	9.0 (2.08)	0-53.3	2.1-18
Silver	n/a	n/a	3.0 (4.63)	n/a	n/a
Zinc	160 (500)	215 (141)	112.0 (4.59)	56-929	51-960

Sources of Research Cited by Shaver et al. 2007:
[a]NURP, 1983. [b]Schiff et al., 2001. [c]Pitt et al., 2002. [d]Barrett et al., 1998. [e]SCCRP, 2001

Total metals = dissolved + particulate

Typical concentrations are small, all < 215 *u*g/L (ppb) = < .215 ppm

Max concentrations are much larger than mean or median, up 7000 ppb = 7 ppm

Cu, Pb and Zn have highest concentrations

Very large variations in everything

Table 1. Summary of EPA National Recommended Water Quality Criteria for Various Metals (Source: EPA 2005)

Priority Pollutant (Dissolved, unless otherwise noted)	Freshwater Criteria Hardness Based Standard?	Freshwater Aquatic Life	
		Acute ppb	Chronic ppb
Cadmium	yes	2	0.25
Chromium (III)	yes	570	74
Chromium (VI)	no	16	11
Copper	no	Based on biotic ligand model	
Lead	yes	65 (note 2)	2.5 (note 2)
Mercury, Total	no	1.4	0.77
Nickel	yes	470	52
Silver	yes	3.2	--
Zinc	yes	120	120

Notes:
1) See Drinking Water Regulations (40 CFR 141) for most cu
2) Criteria under revision.
3) Hardness-based standards vary substantially based on site
based on hardness = 100 mg/L for purposes of this table.

Both acute and chronic concentrations are comparable to road runoff concentrations in previous table

But criteria apply to <u>dissolved phase only</u>.

Combined or Synergistic or effects?

Hardness mitigates metals toxicity, because Ca^{2+} and Mg^{2+} help keep fish from absorbing **metals** such as lead, arsenic, and cadmium into their bloodstream through their gills. The greater the **hardness**. the harder it is for **toxic metals** to be absorbed through the gills.

Table 4. Typical Levels of Metals Found in Stormwater Runoff (ug/L)
(Source: *Fundamentals of Urban Runoff Management*, Shaver et al. 2007)

Priority Pollutant (Dissolved, unless otherwise noted)	Freshwater Aquatic Life		Stormwater Median (90th Percentile)[a]	Mean (sd)[b]	Median (Cov) Urban Stormwater[c]	Range for Highway Runoff[d]	Range for Parking lot Runoff[e]
	Acute	Chronic					
Cadmium	2	0.25	n/a	1.1 (0.7)	1.0 (4.42)	0-40	0.5-3.3
Chromium (III)	570	74	n/a	7.2 (2.8)	7.0 (1.47)	0-40	1.9-10
Chromium (VI)	16	11					
Copper	Based on biotic ligand model		34 (93)	33 (19)	16.0 (2.24)	22-7033	8.9-78
Lead	65 (note 2)	2.5 (note 2)	144 (350)	70 (48)	15.9 (1.89)	73-1780	10-59
Mercury, Total	1.4	0.77	n/a	n/a	0.2 (1.17)	0-0.322	n/a
Nickel	470	52	n/a	10 (2.8)	9.0 (2.08)	0-53.3	2.1-18
Silver	3.2	--	n/a	n/a	3.0 (4.63)	n/a	n/a
Zinc	120	120	160 (500)	215 (141)	112.0 (4.59)	56-929	51-960

Metals in stormwater may occur in particulate, colloidal (very small particles) of dissolved forms,

Many metals in urban runoff are predominantly associated with particulates

Particulates are "easy" to remove by physical processes like swirling, settling

Pollutants can move between dissolved and particulate phases based on pH and redox

Colloidal and dissolved forms are more toxic AND harder to remove

One stormwater best management practice (BMP): Catch-basin insert (filter bag)

Advantages
- Widely applicable
- Low cost
- Easy installation
- Relatively easy maintenance
- Effective at removing solids

Weakness
- Not effective at removing dissolved metals and petroleum hydrocarbons

To remove of dissolved pollutants, we filled the bag with an adsorbent media: residuals from coagulation/flocculation process in drinking water (not sewage) treatment plants, i. e. water treatment residuals (WTRs)

- **Waste byproduct of drinking water treatment, typically landfilled or incinerated**
- **Available at no cost**
- **Primary components: Al or Fe hydroxides**
- **Very high specific surface; highly effective in metal adsorption**
- **2 mega tons generated everyday in the US (Prakash and Sengupta, 2003)**
- **Non-hazardous waste material**
- **Air-dried, ground til passing 2-mm seive**

Preliminary studies on potential remediation of acid mine drainage-impacted soils by amendment with drinking-water treatment residuals A Roychowdhury, D Sarkar, R Datta Remediation Journal 28 (3), 75-82	1	2018
Water treatment residuals and scrap tire rubber combination as "novel" green sorbents for removal of common metals from polluted urban stormwater runoff Y Deng, C Morris, S Rakshit, ER Landa, D Sarkar Water Environment Research 88 (6), 500-509	2 *	2016
Water treatment residuals coated wood mulch for alleviation of toxic metals and phosphorus from polluted urban stormwater runoff H Soleimanifer, Y Deng, L Wu, D Sarkar Chemosphere 154, 289-292	11	2016
Drinking water treatment residual amendment lowers inorganic arsenic bioaccessibility in contaminated soils: a long-term study R Nagar, D Sarkar, P Punamiya, R Datta Water, Air, & Soil Pollution 226 (11), 366	6	2015
Effectiveness of aluminum-based drinking water treatment residuals as a novel sorbent to remove tetracyclines from aqueous medium P Punamiya, D Sarkar, S Rakshit, R Datta Journal of environmental quality 42 (5), 1449-1459	19	2013
Effect of solution chemistry on arsenic sorption by Fe-and Al-based drinking-water treatment residuals R Nagar, D Sarkar, KC Makris, R Datta Chemosphere 78 (8), 1028-1035	81	2010
Aluminum-based drinking-water treatment residuals: a novel sorbent for perchlorate removal KC Makris, D Sarkar, R Datta Environmental Pollution 140 (1), 9-12	76	2006
Arsenic immobilization in soils amended with drinking-water treatment residuals D Sarkar, KC Makris, V Vandanapu, R Datta Environmental Pollution 146 (2), 414-419	68	2007

Dr. Dibyendu Sarkar of Stevens Institute has been studying the use of WTRs for pollutant removal for many years

Aluminum-based water treatment residuals (Al-WTR) do not produce toxic leachate

Toxicity Characteristic Leaching Procedure (TCLP)

TCLP values (mg/L) of RCRA 8 metals		
Analyte (mg L^{-1})	**USEPA Limit (mg L^{-1})**	**Al-WTR**
Arsenic	5	1.93
Barium	100	1.44
Cadmium	1	0.028
Chromium	5	0.023
Lead	5	0.239
Mercury	0.2	< MDL**
Selenium	1	< MDL
Silver	5	0.001
Copper	10	0.05
Zinc	NR	0.244
Aluminum	NR	228.9
Iron	NR	2.308

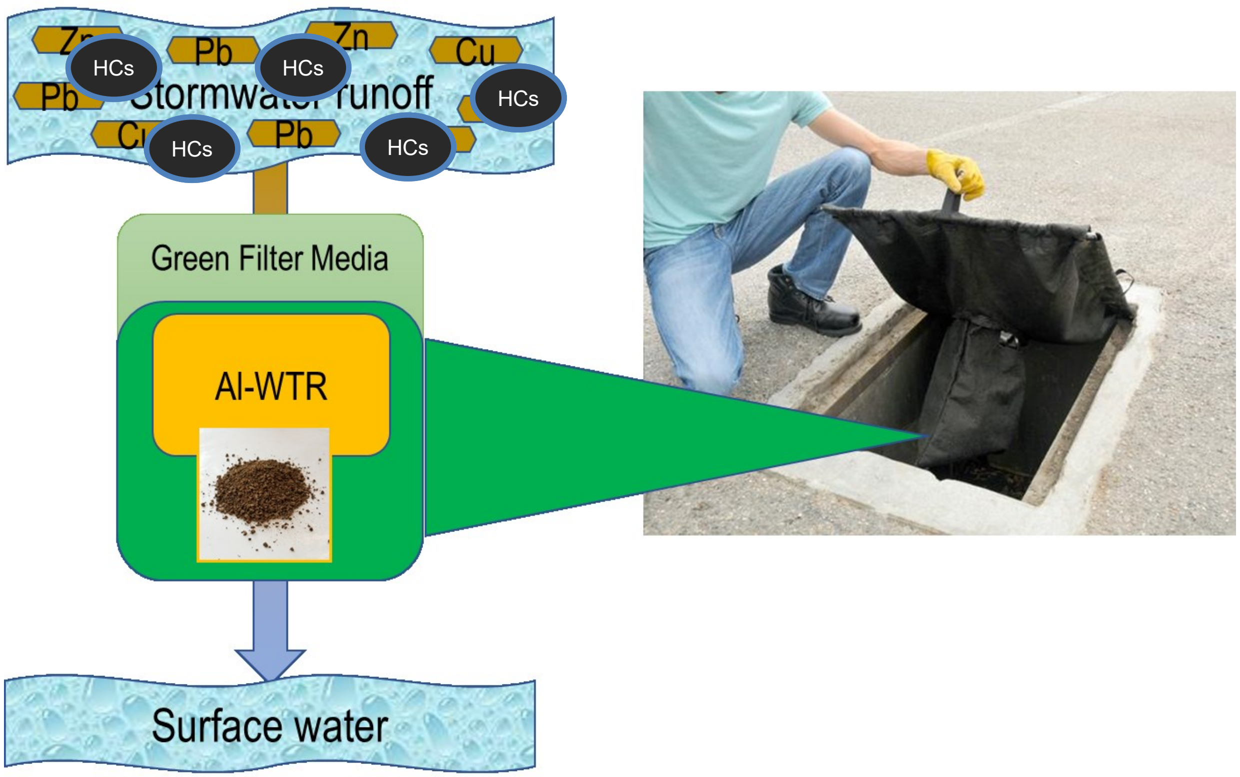
Source of Al-WTR: New Jersey American Water (NJAW) Water Treatment Plant in Delran, NJ.

MDL: minimum detection level

NR: non-regulated

Study Objective

To develop and test catch-basin insert filled with WTRs to remove heavy metals and petroleum hydrocarbons from pavement runoff



Project phases

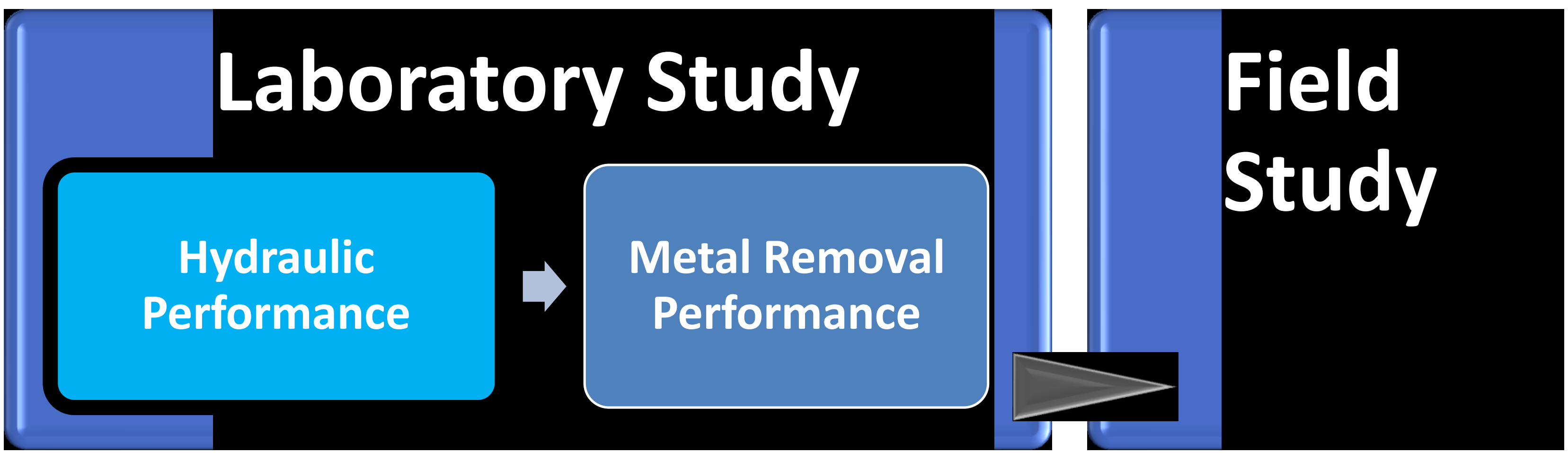
Laboratory Study

Hydraulic Performance

Metal Removal Performance

Field Study

Lab study: Hydraulic Performance Column Study



Lab study: Hydraulic Performance Permeameter Study

A limitation of WTRs are their low permeability, so we mixed them sand

Tested 4 different mixing ratios

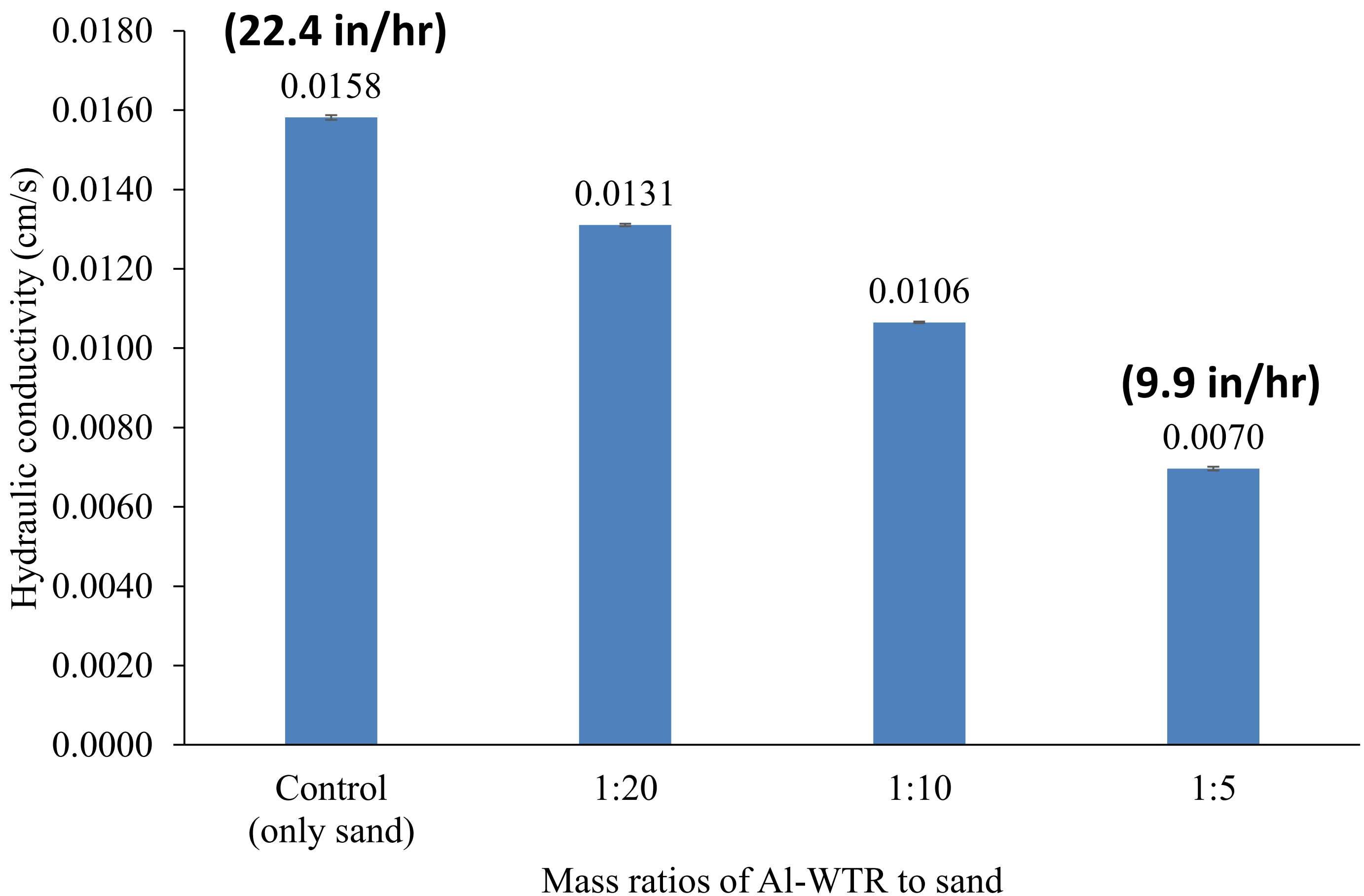
Al-WTR: Sand by weight

0:1 (pure sand)
1:5
1:10
1:20

Al-WTR

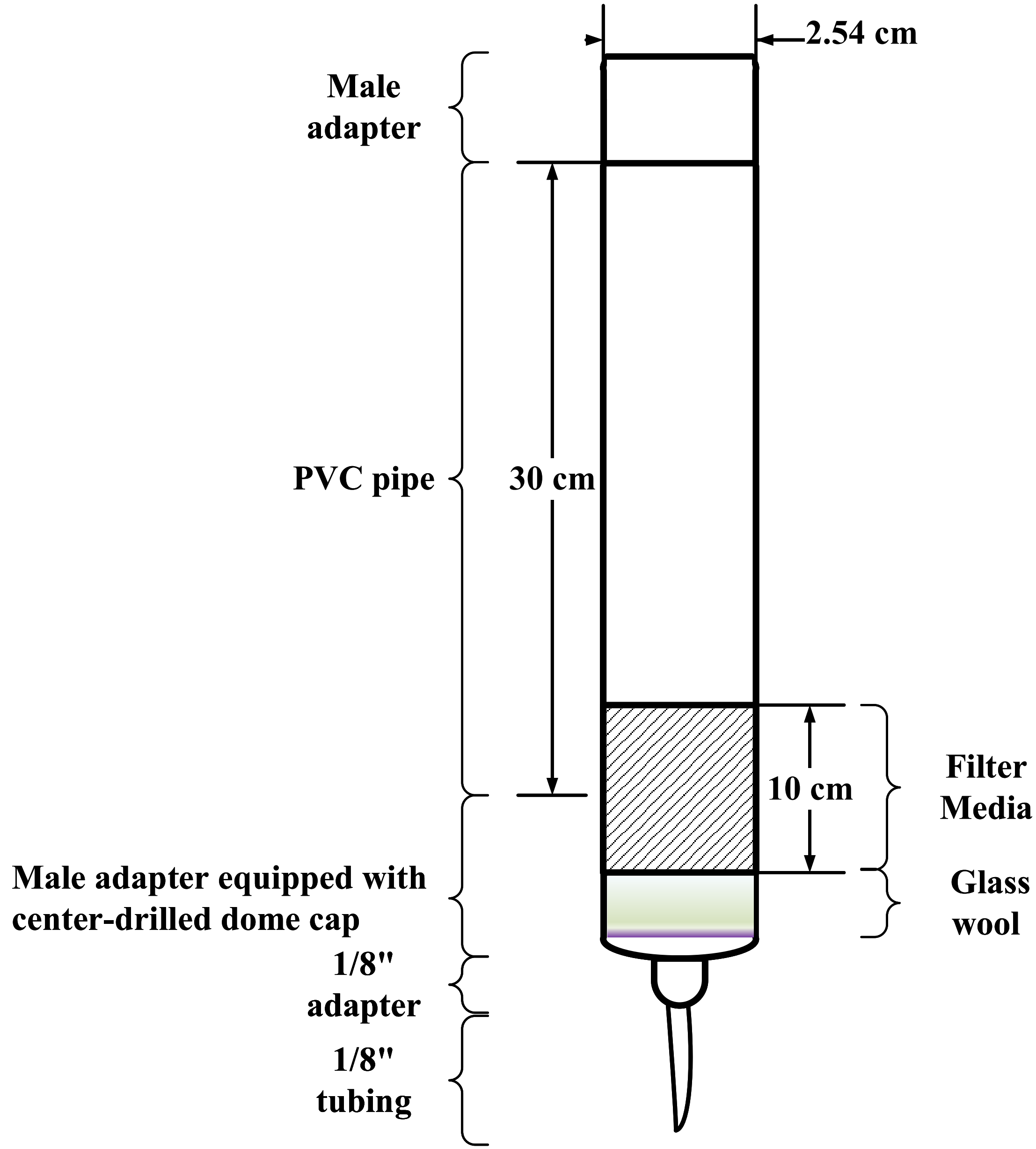
Sand

Lab study: Hydraulic Performance Permeameter Study



Mixing more sand with Al-WTR improves permeability

Lab study: Hydraulic Performance Column Study



Lab study: Hydraulic Performance Column Study

A limitation of WTRs is poor ability to remove hydrocarbons, so we add granulated carbon

Mono-layer media

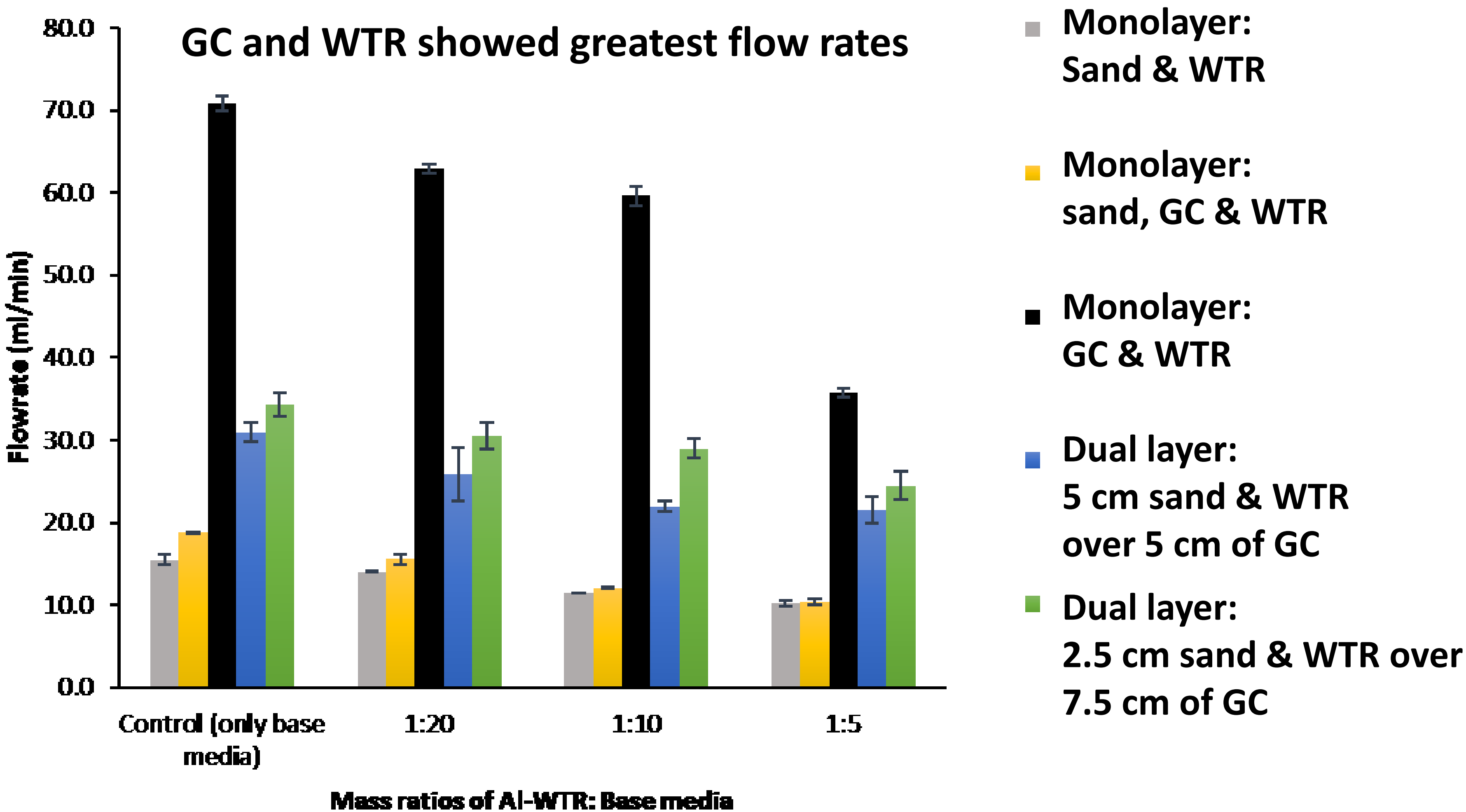
- Sand & Al-WTR
- Sand, GC & Al-WTR
- GC & Al-WTR

Dual-layer media

- 2.5 cm of Al-WTR & sand over a 7.5 cm layer of GC
- 5 cm of Al-WTR & sand over a 5 cm layer of GC

4 different mixing ratios Al-WTR: Base media (w/w): 1:20, 1:10, 1:5 and 0:1

Lab study: Hydraulic Performance Column Study



Lab study: Metal Removal Performance

Laboratory Study

Hydraulic performance

Metal Removal Performance

Field Study

Lab study: Metal Removal Performance

Synthetic stormwater

- Cu - 6.36 mg/L (Source: Cu $(NO_3)_2$ •$2.5H_2O$)
- Pb - 8.16 mg/L (Source: $Pb(NO_3)_2$)
- Zn - 11.70 mg/L (Source: $Zn(NO_3)_2$•$6H_2O$)

(Exaggerated 100 times concentration of stormwater collected from Toms River parking lot)

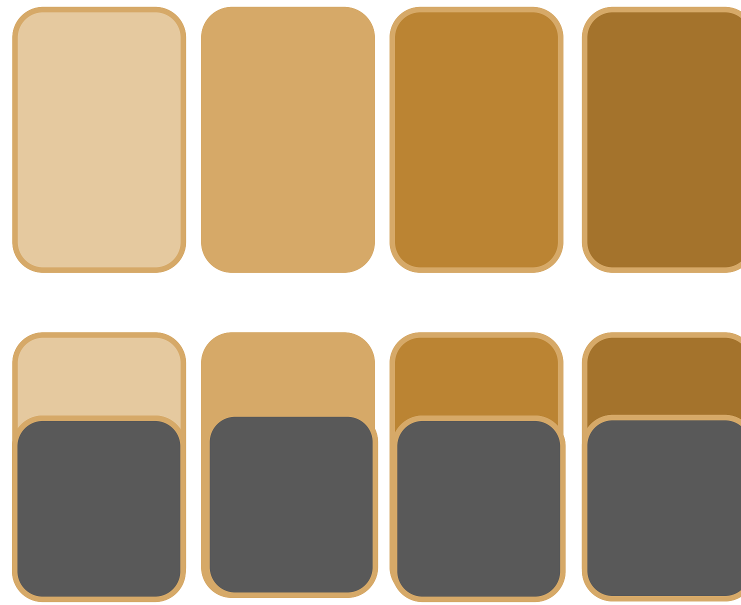
Parameter	Value
Bed Height (cm)	10
Bed Volume (mL)	50.7
Flow Rate (mL/min)	8
Sample Collection	Every 5 minutes for the first 20 minutes, followed by geometric progression

Lab study: Metal Removal Performance

Al-WTR: sand weight ratio	0:1 (only sand)	1:20	1:10	1:5

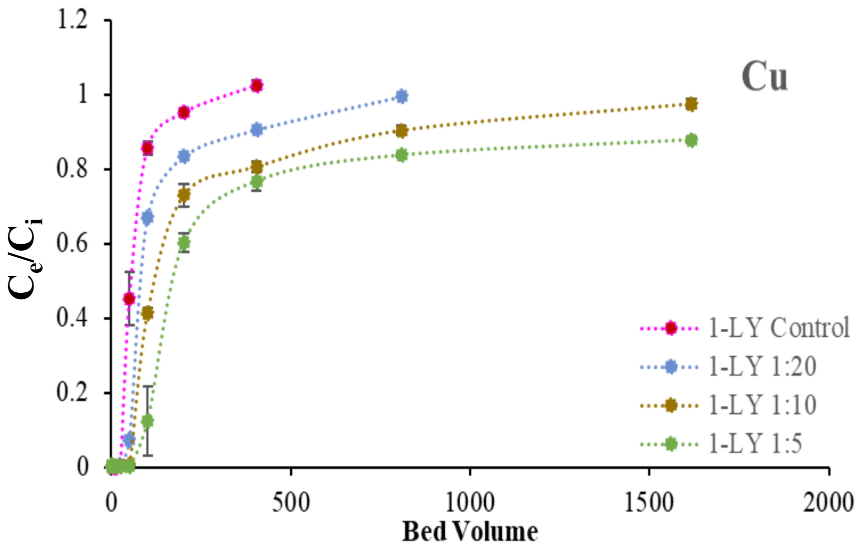
Mono-layer:
Sand & WTR

Dual-layer:
2.5 cm of sand & WTR
over 7.5 cm of GC

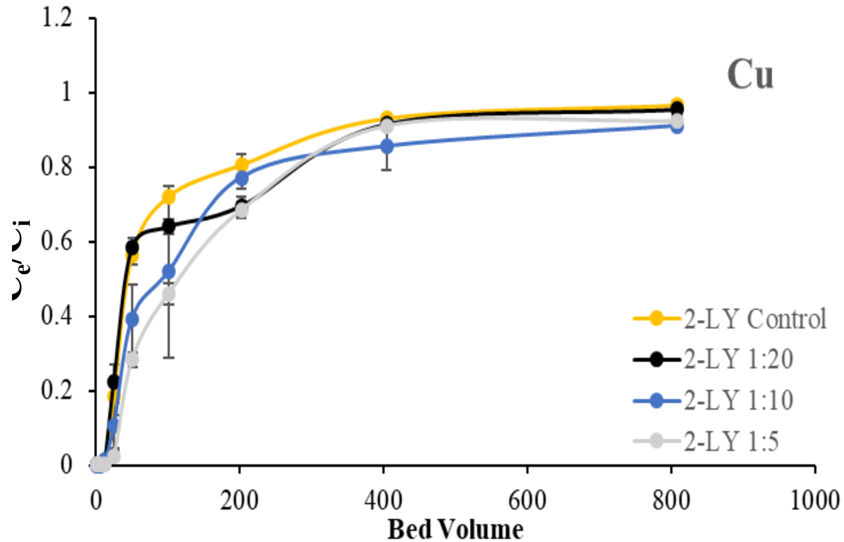


Lab study: Copper Removal Performance

Mono-layer:
Sand & WTR



Dual-layer:
2.5 cm of sand & WTR over
7.5 cm of GC

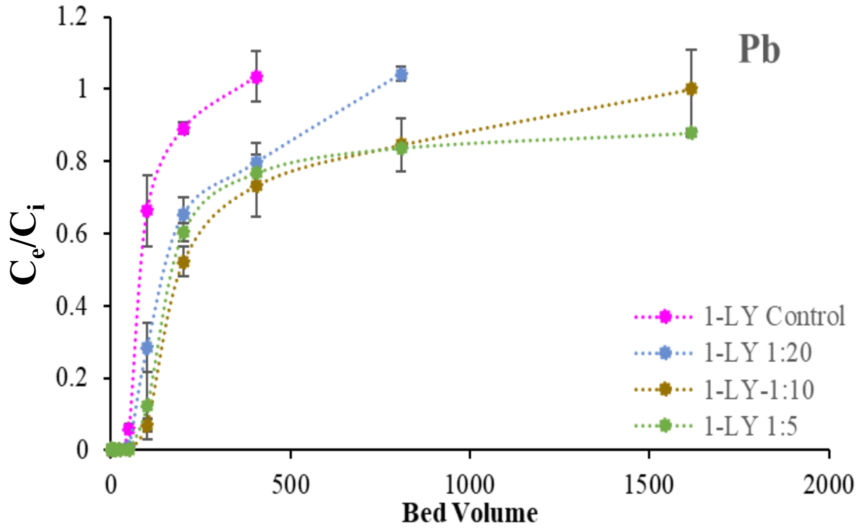


As portion of Al-WTR increases, removal capability of copper increases.

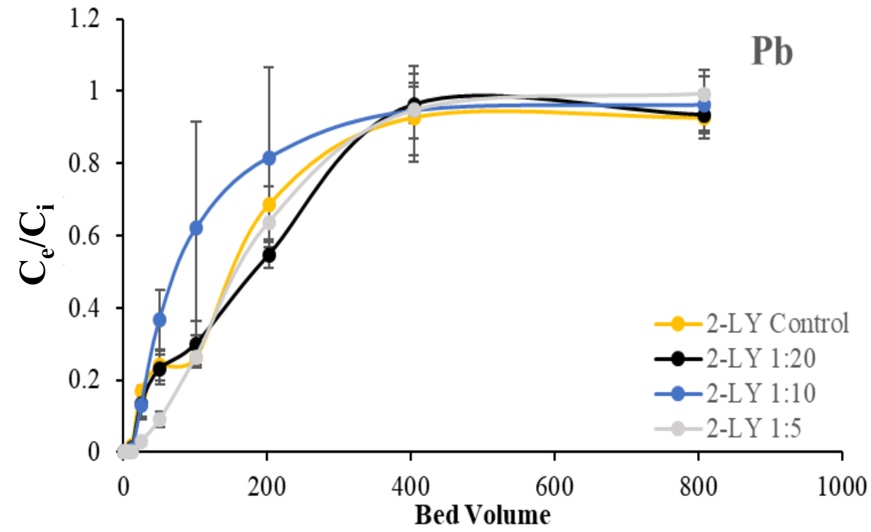
GC masks the effect of increasing portion of Al-WTR

Lab study: Lead Removal Performance

Mono-layer:
sand-based media

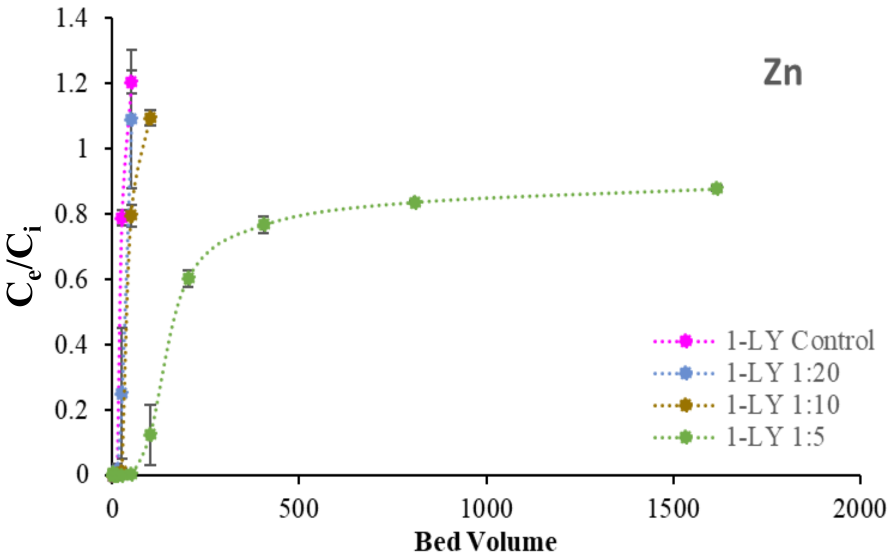


Dual-layer:
2.5 cm of sand-based media over
7.5 cm of CM

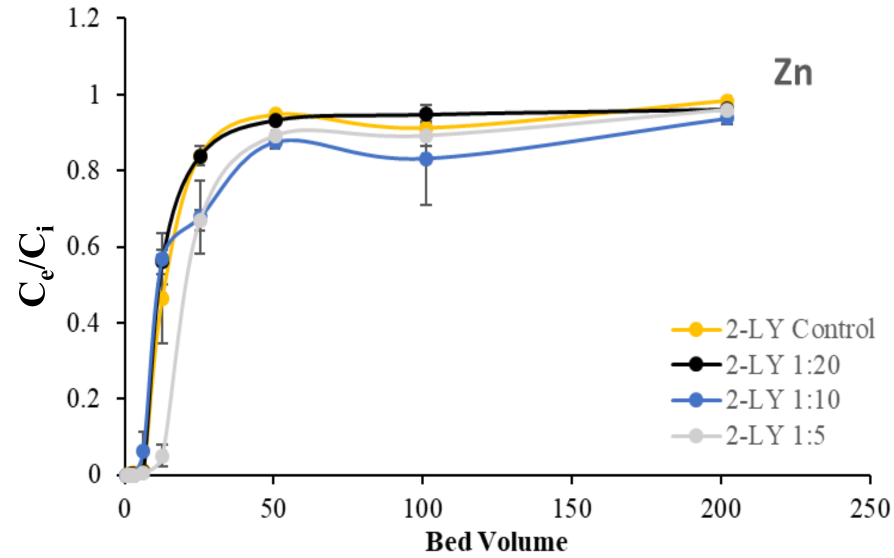


Lab study: Zinc Removal Performance

Mono-layer:
sand-based media



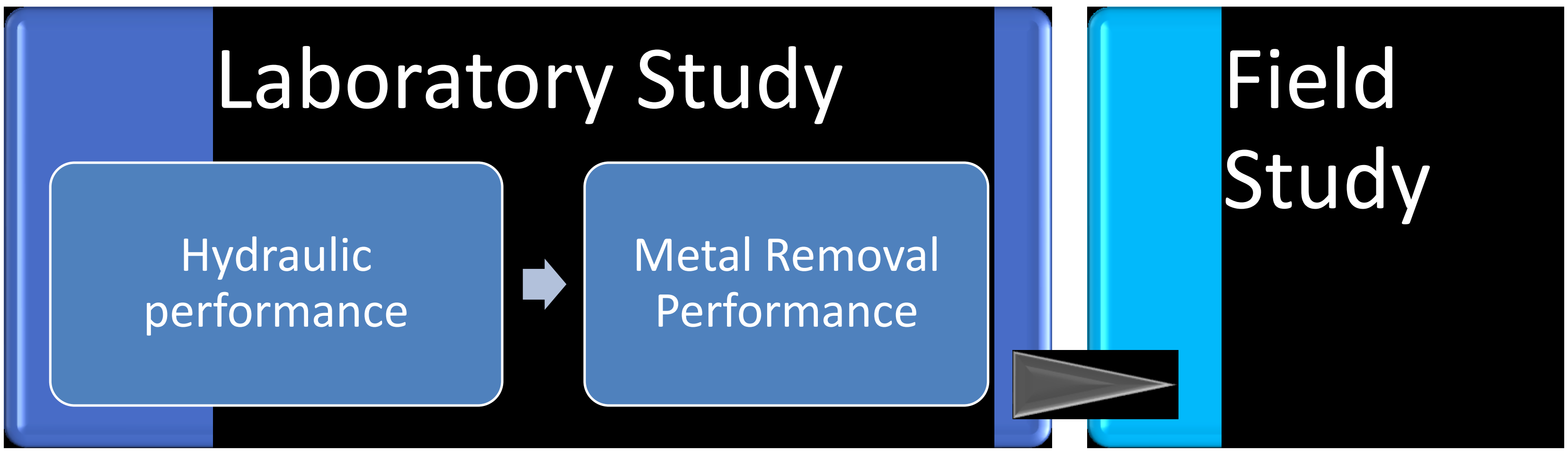
Dual-layer:
2.5 cm of sand-based media over
7.5 cm of CM



Summary: Laboratory studies

- Incorporating sand and CM with Al-WTR increased the permeability of the filter media, resulting in a higher flowrate.
- This study showed that metal removal capability was enhanced by increasing the amount of Al-WTR.
- The 2.5 cm of Al-WTR-amended sand over a 7.5 cm layer of CM at a mixing ratio of 1:20 was the optimal filter media based on hydraulic and metals removal performance

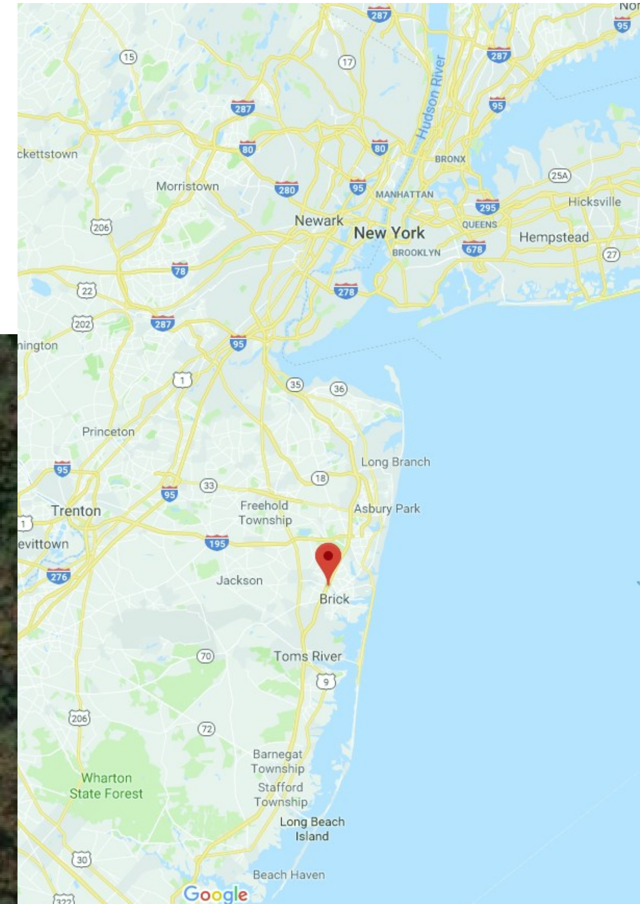
Field study



Media selected used for field study:
Dual-layer: 2.5 cm of sand & WTR at 1:20 ratio over 7.5 cm of CM

Field study: Study area

Much thanks to the Township of Brick for providing the field site: Brick Town Hall



Barnegat Bay watershed was a priority for the funding program

Field study: Setup

Field testing setup had to be able to:

- **Retain and withstand the weight of the filter media**
- **Direct water to pass through the filter media**
- **Allow us to sample water before and after passing through the filter media**
- **Allow bypass of high flows to prevent flooding in the case of very big storm**
- **Fit catch basins at the site**

Field study: Custom-made insert with frame. Materials cost ~$300

Field study: Setup

Field testing setup had to be able to:

- ✓ Retain and withstand the weight of the filter media
- Direct water to pass through the filter media
- Allow us to sample water before and after passing through the filter media
- Prevent flooding in the case of big storm events through overflow window
- Fit catch basins at the site

Field study: Setup

Field testing setup had to be able to:

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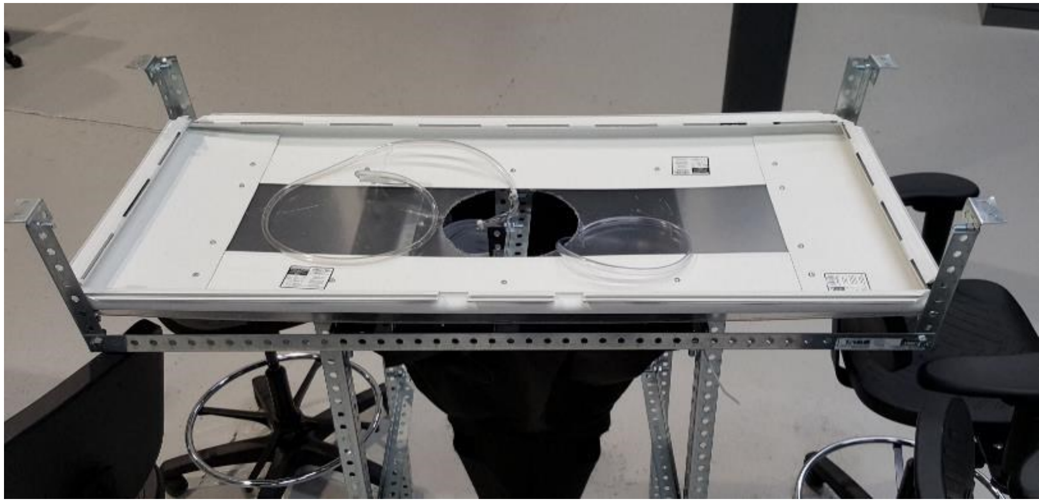

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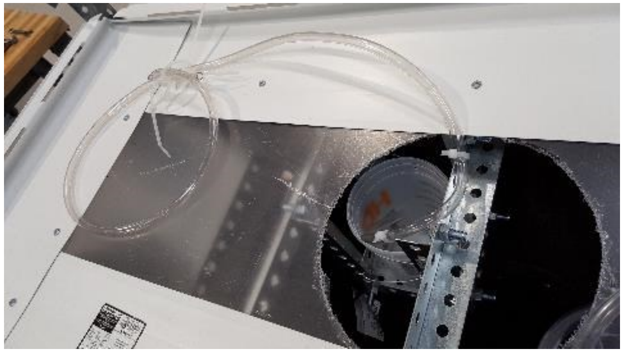

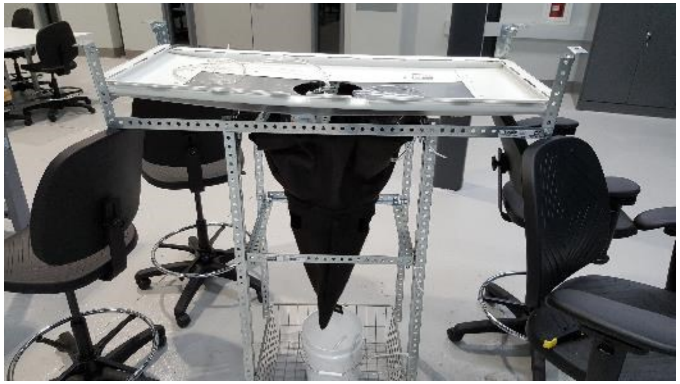

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Field study: Setup

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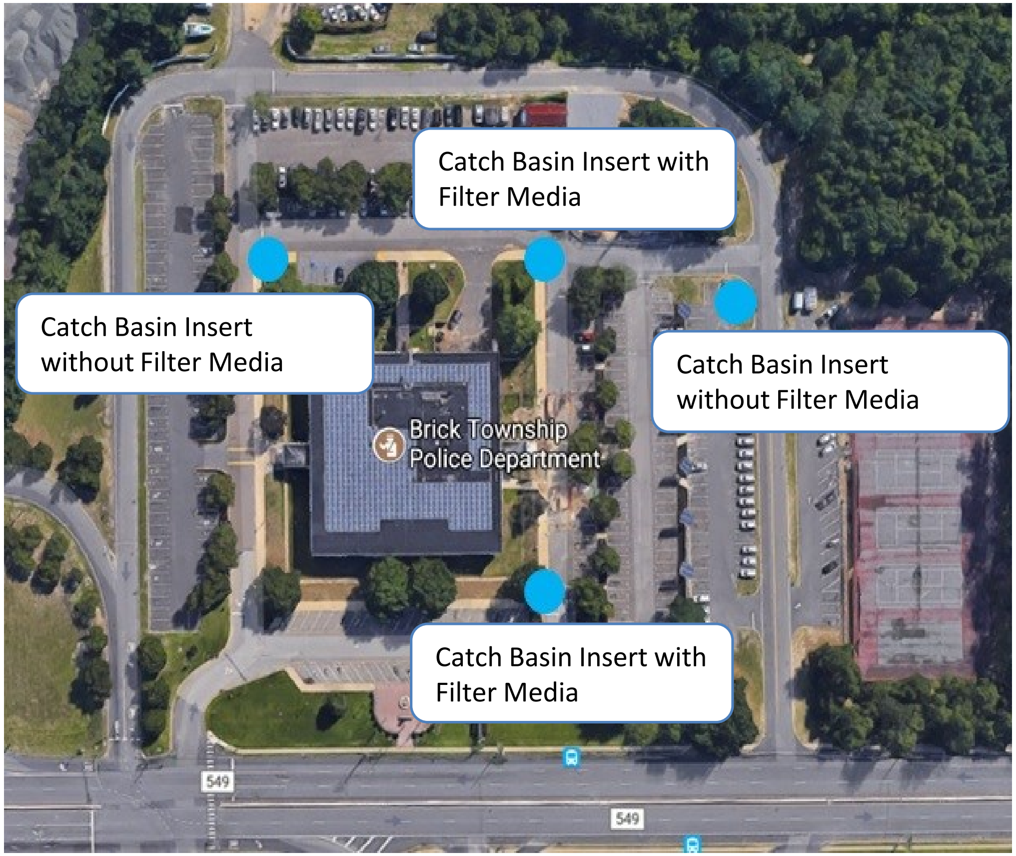
- ✓ Fit catch basins at the site

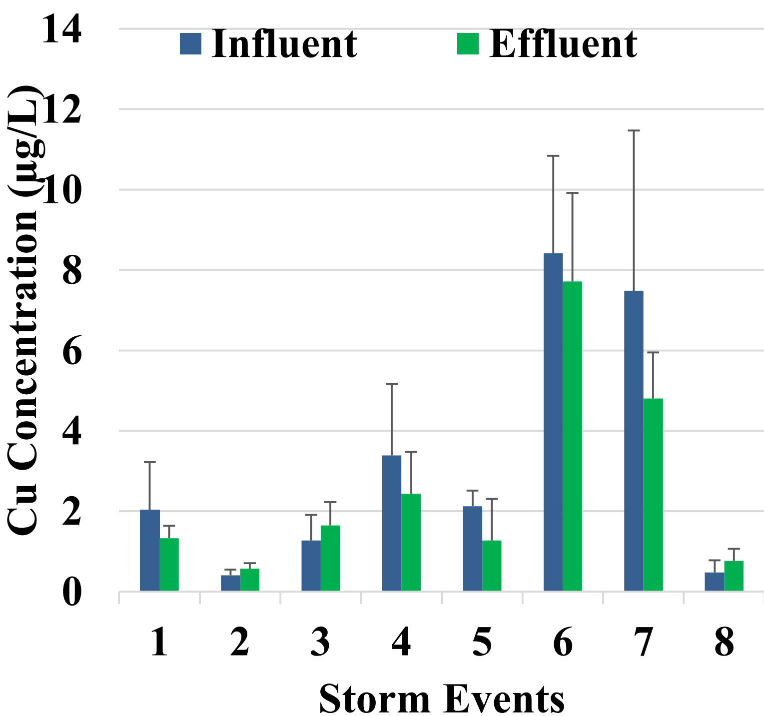
Field study: location of stormdrain inlets



Study Period: 4 months (August 2017 – November 2017), 8 storm events
Measured Parameters: Turbidity, pH, Dissolved Cu, Dissolved Pb, Dissolved Zn, and TPHs

Field study: Dissolved copper

Inserts with media



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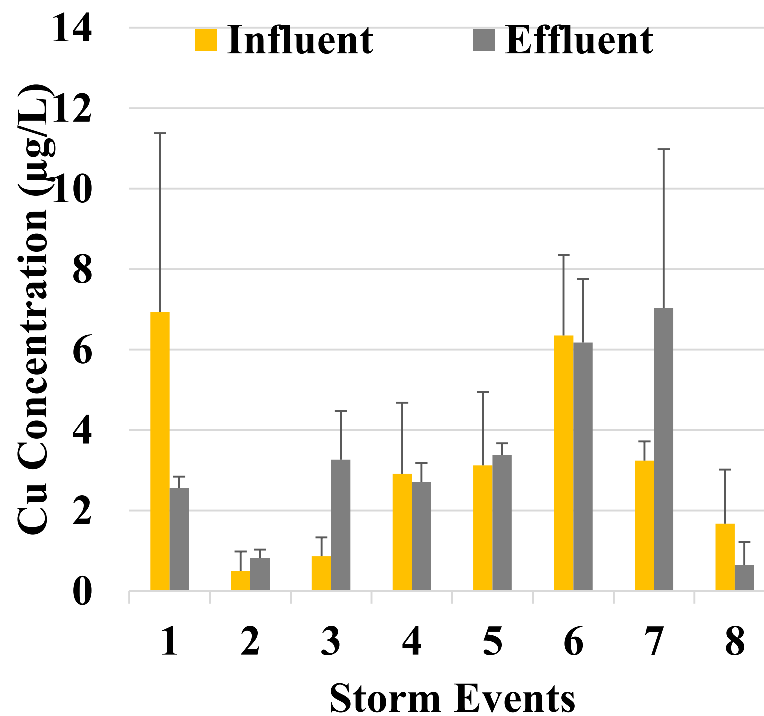
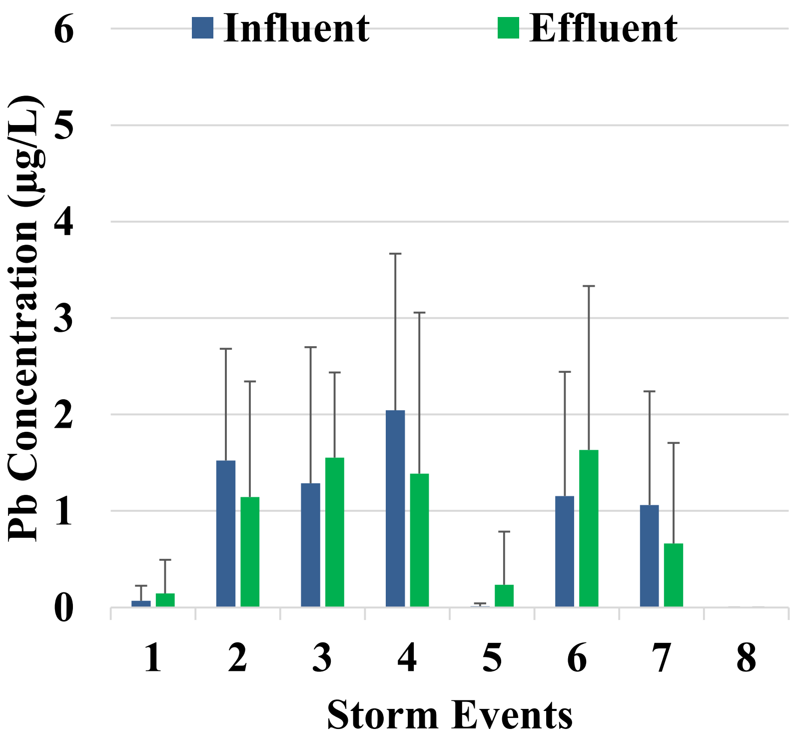


Field study: Dissolved lead

Inserts with media



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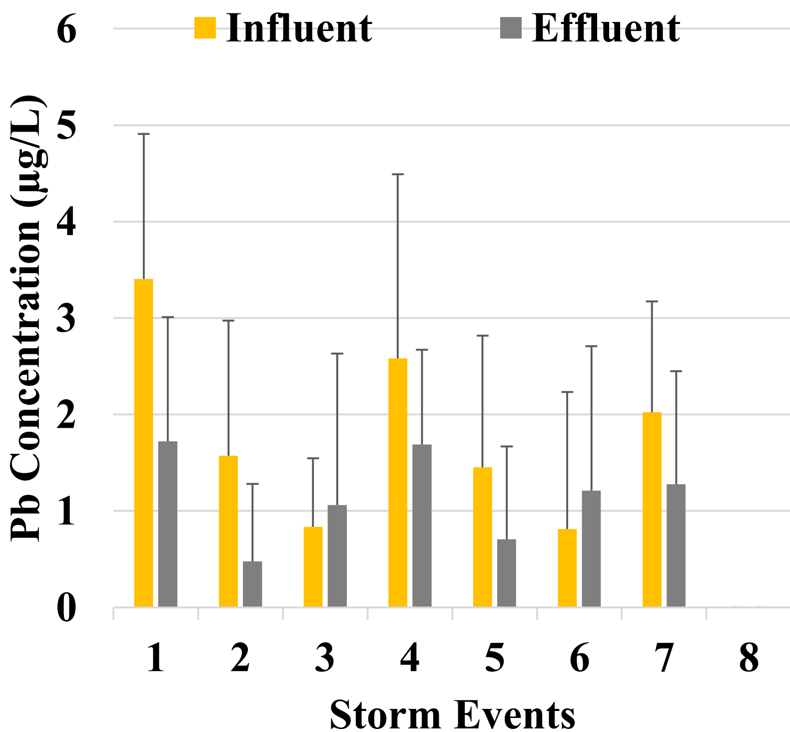
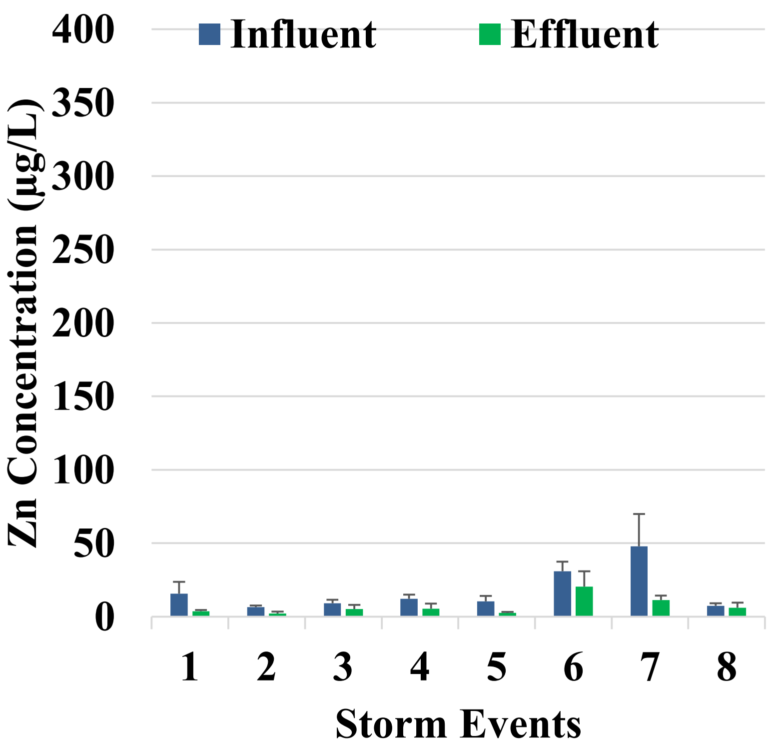


Field study: Dissolved zinc

Inserts with media



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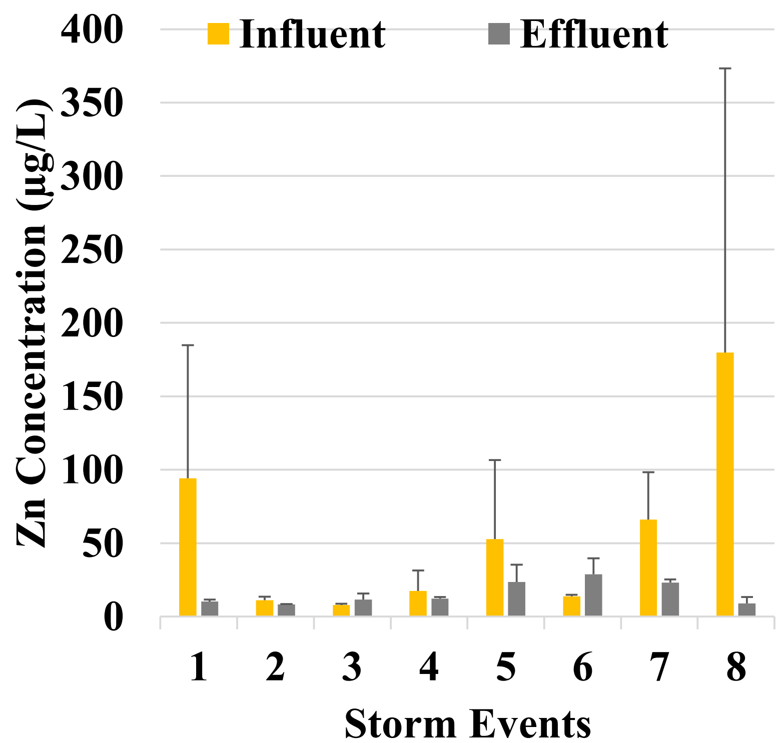
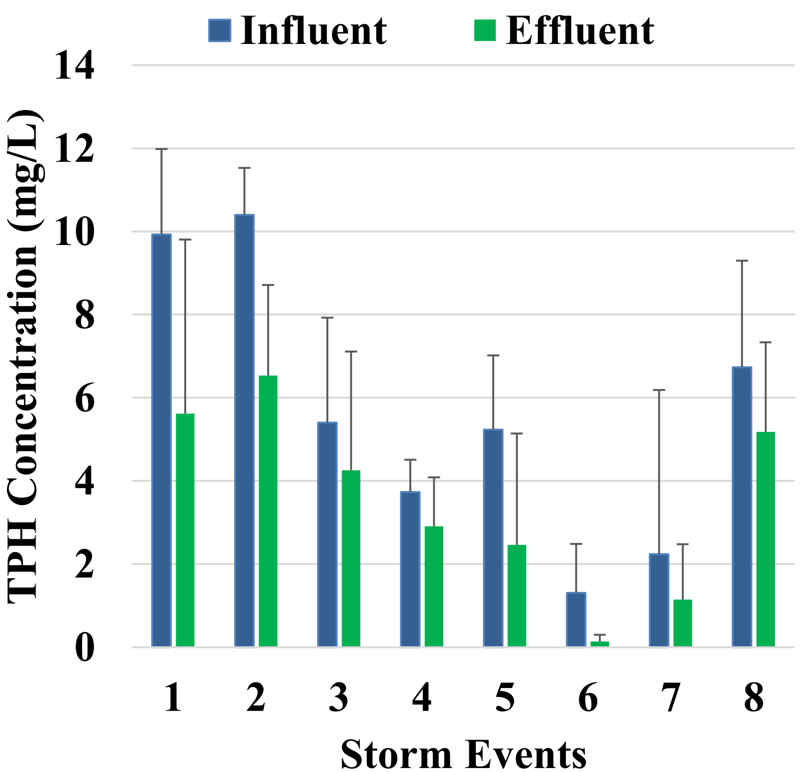


Field study: Total Petroleum Hydrocarbons (TPH)

Inserts with media



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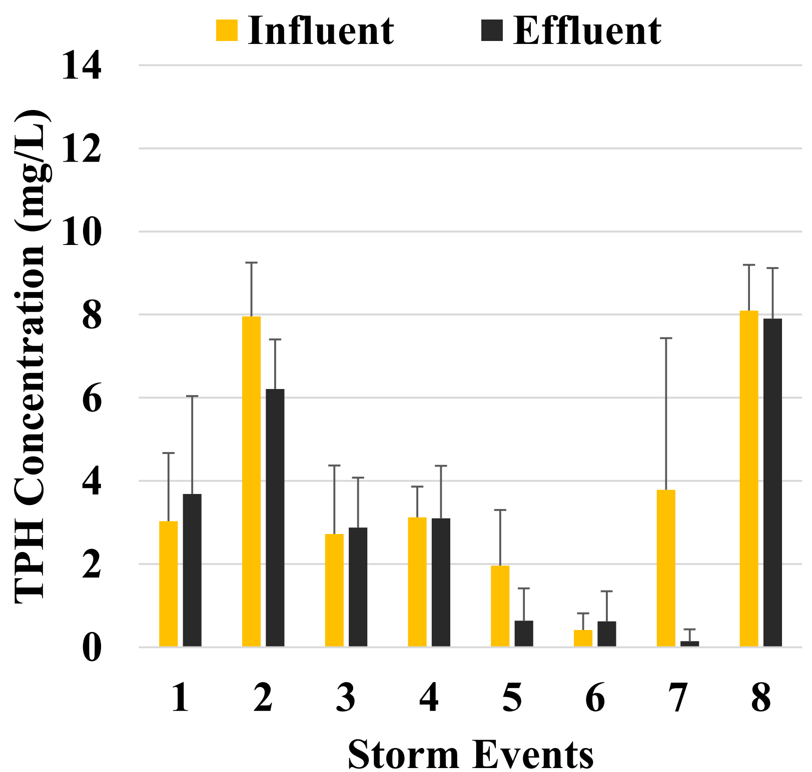
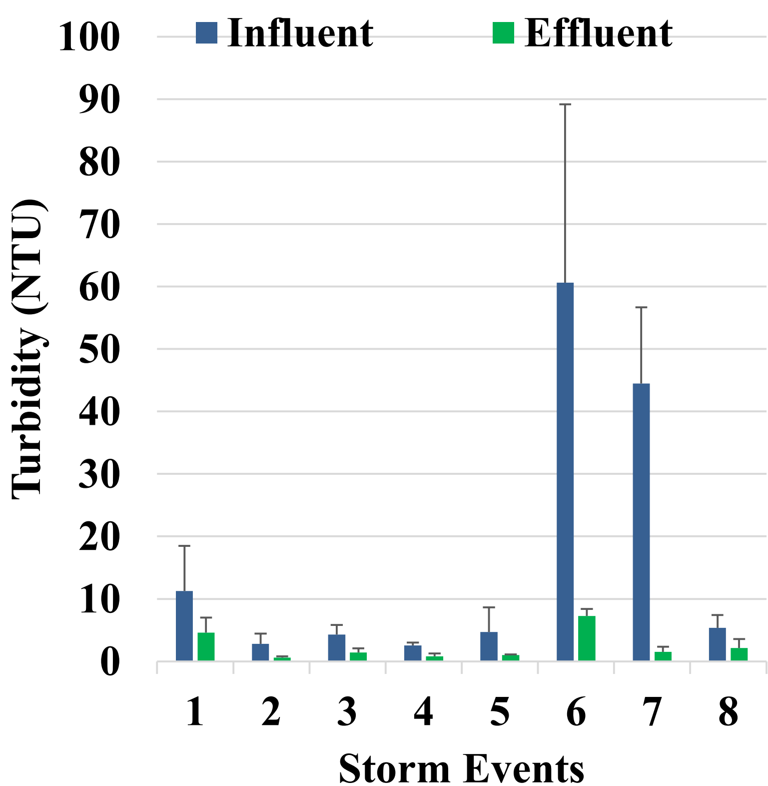


Field study: Turbidity

Inserts with media



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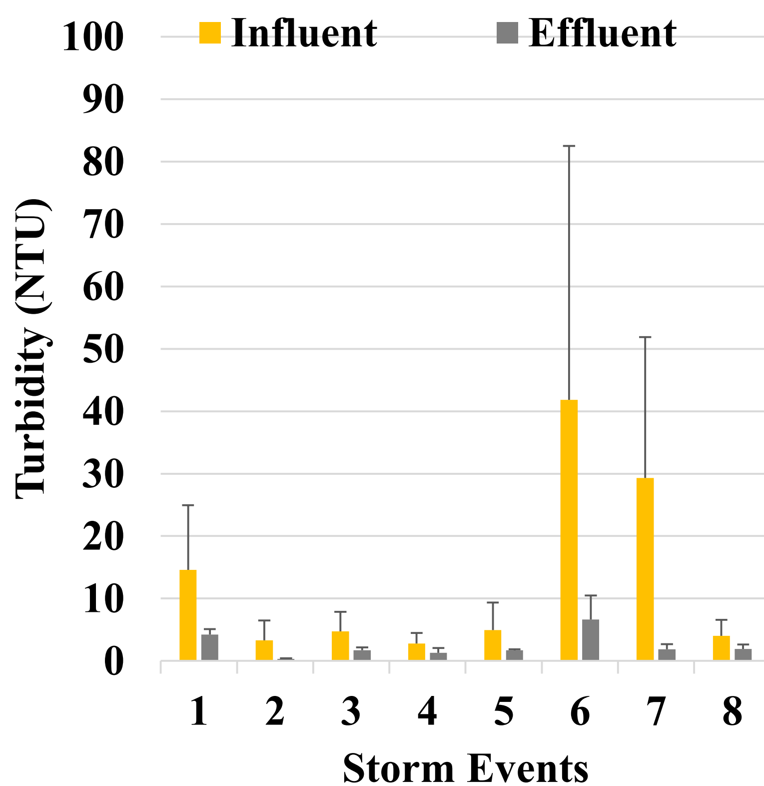
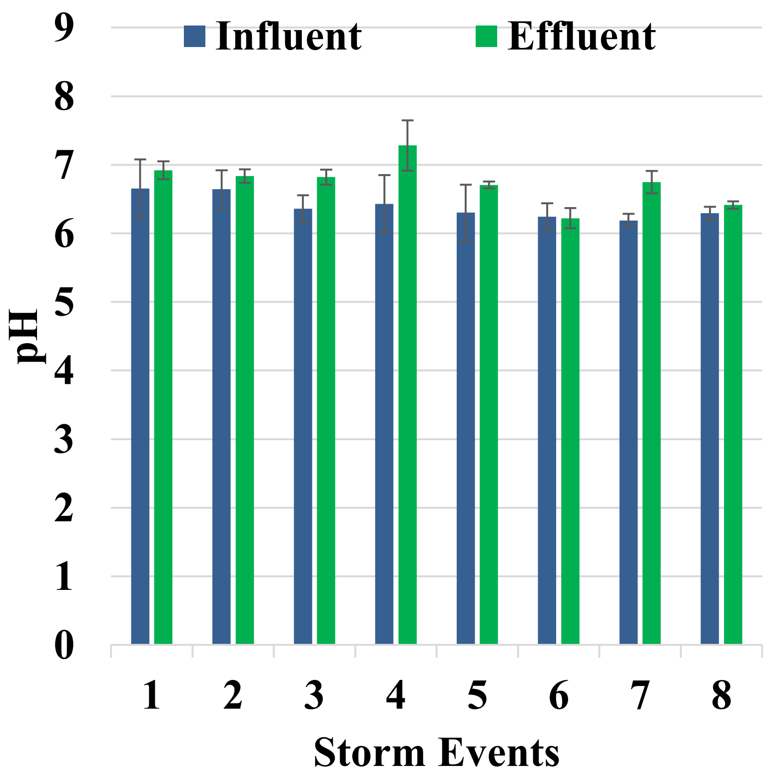
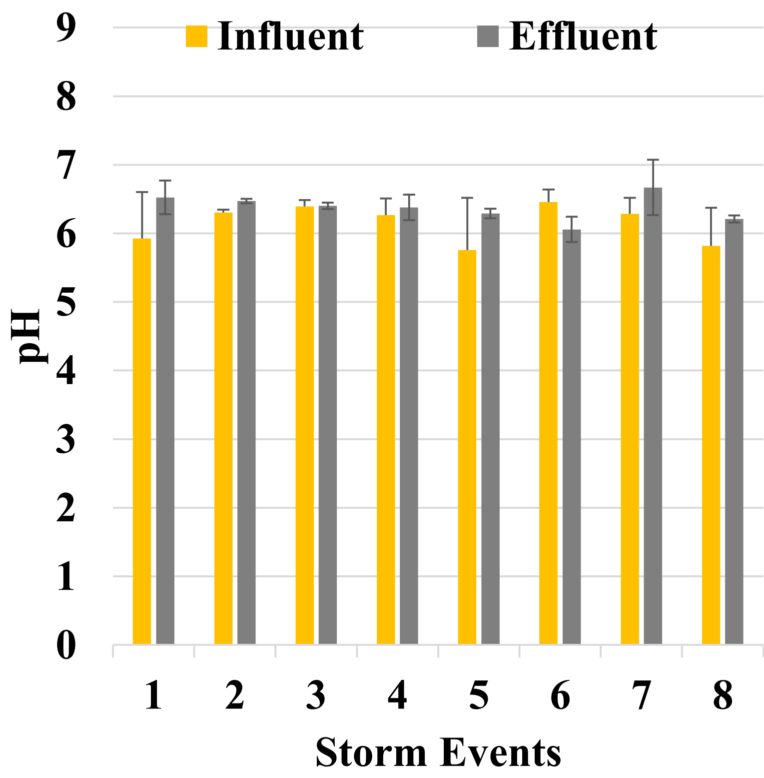


Field study: pH

Inserts with media



Inserts without media



Summary: Field study

	Median concentration					
	Inlet		Outlet		% Reduction	
Pollutant	With media	Without media	With media	Without media	With media	Without media
Cu (µg/L)	2.0	2.7	1.6	2.9	17	-9
Pb (µg/L)	0.1	1.3	0.0	0.6	69	56
Zn (µg/L)	11.5	13.1	4.0	12.4	65	5
TPH (mg/L)	5.1	3.4	2.8	2.8	46	18
Turbidity (NTU)	6.1	5.7	1.1	1.8	82	69
pH	6.4	6.3	6.8	6.3	-6	0

Median outlet pollutant concentrations with media were less than without media for all pollutants except TPH (tie)

Percent reduction in median pollutant concentrations was greater with media than without media for all pollutants

Flow through catch basin inserts with media was comparable with those without media and no pooling of water was observed.

Recent advance at Dr. Sarkar's lab at Stevens Institute: production of granulated Al WTR to provide both adsorption and flow.

Acknowledgements

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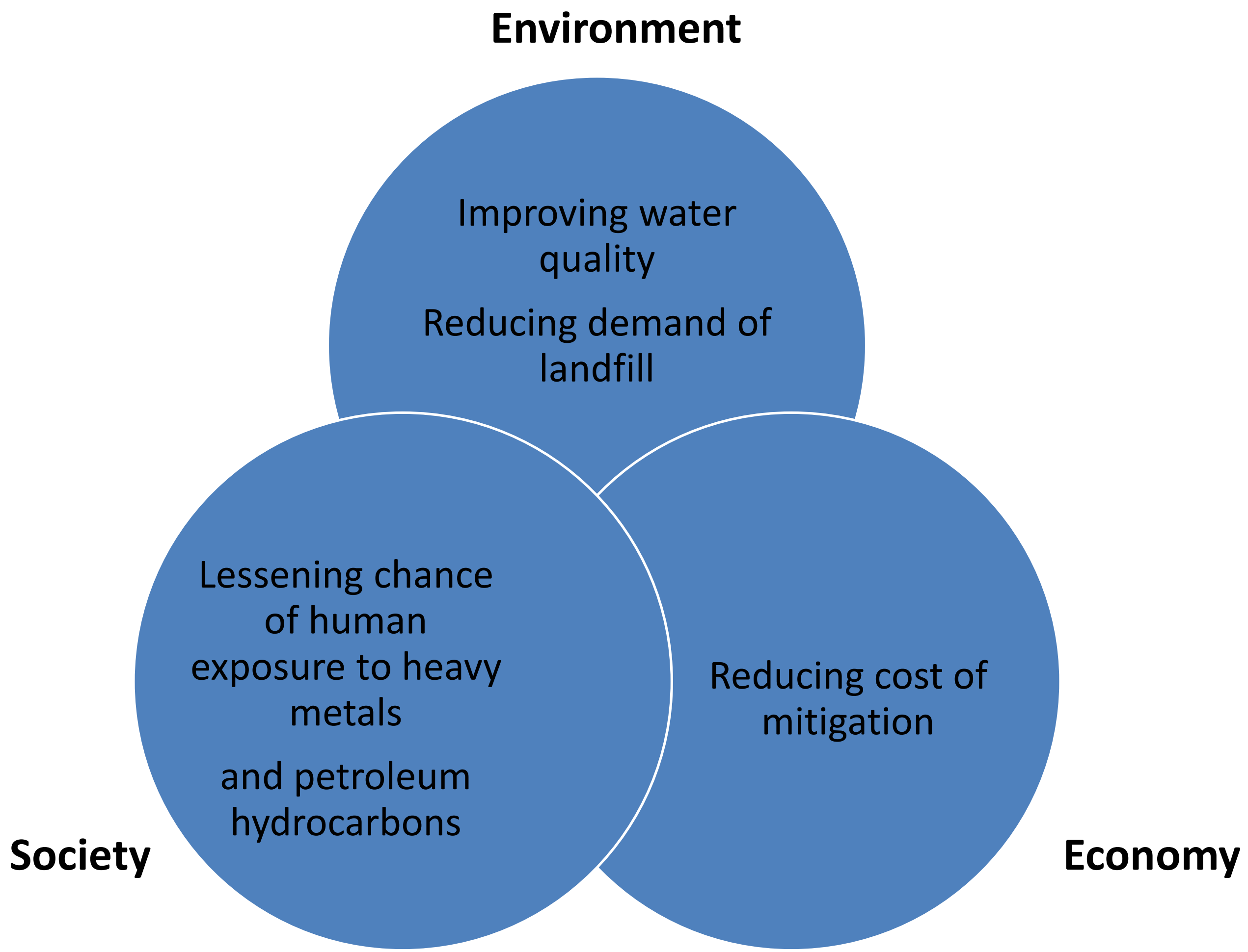
Table 4. Typical Levels of Metals Found in Stormwater Runoff (ug/L)
(Source: *Fundamentals of Urban Runoff Management*, Shaver et al. 2007)

Metal	Stormwater Median (90th Percentile)[a]	Mean (sd)[b]	Median (Cov) Urban Stormwater[c]	Range for Highway Runoff[d]	Range for Parking lot Runoff[e]
Arsenic	n/a	5.9 (2.8)	3.3 (2.42)	0-58	n/a
Cadmium	n/a	1.1 (0.7)	1.0 (4.42)	0-40	0.5-3.3
Chromium	n/a	7.2 (2.8)	7.0 (1.47)	0-40	1.9-10
Copper	34 (93)	33 (19)	16.0 (2.24)	22-7033	8.9-78
Lead	144 (350)	70 (48)	15.9 (1.89)	73-1780	10-59
Mercury	n/a	n/a	0.2 (1.17)	0-0.322	n/a
Nickel	n/a	10 (2.8)	9.0 (2.08)	0-53.3	2.1-18
Silver	n/a	n/a	3.0 (4.63)	n/a	n/a
Zinc	160 (500)	215 (141)	112.0 (4.59)	56-929	51-960
Sources of Research Cited by Shaver et al. 2007: [a]NURP, 1983. [b]Schiff et al., 2001. [c]Pitt et al., 2002. [d]Barrett et al., 1998. [e]SCCRP, 2001					

Summary: Field study

- The green filter media reduced dissolved metals and petroleum hydrocarbons in stormwater runoff.
- The catch basin insert material captured suspended particulate matter and thereby reduced turbidity in stormwater runoff.
- The green filter media slightly increased the pH of stormwater runoff.
- Intensity and duration of storm events dictated metals and TPH input in storm drains.
- Storm drains in those parts of the parking lot that experienced higher vehicular activities had higher TPH concentrations.

Conclusion


Environment
Improving water quality
Reducing demand of landfill
Lessening chance of human exposure to heavy metals
and petroleum hydrocarbons
Reducing cost of mitigation
Society
Economy